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D.J. Morrison, G.W. Wallis and L.C. Weir

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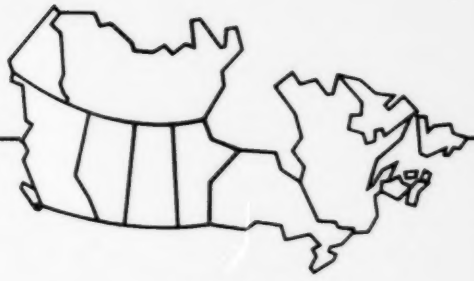

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PLOT 36 FIR

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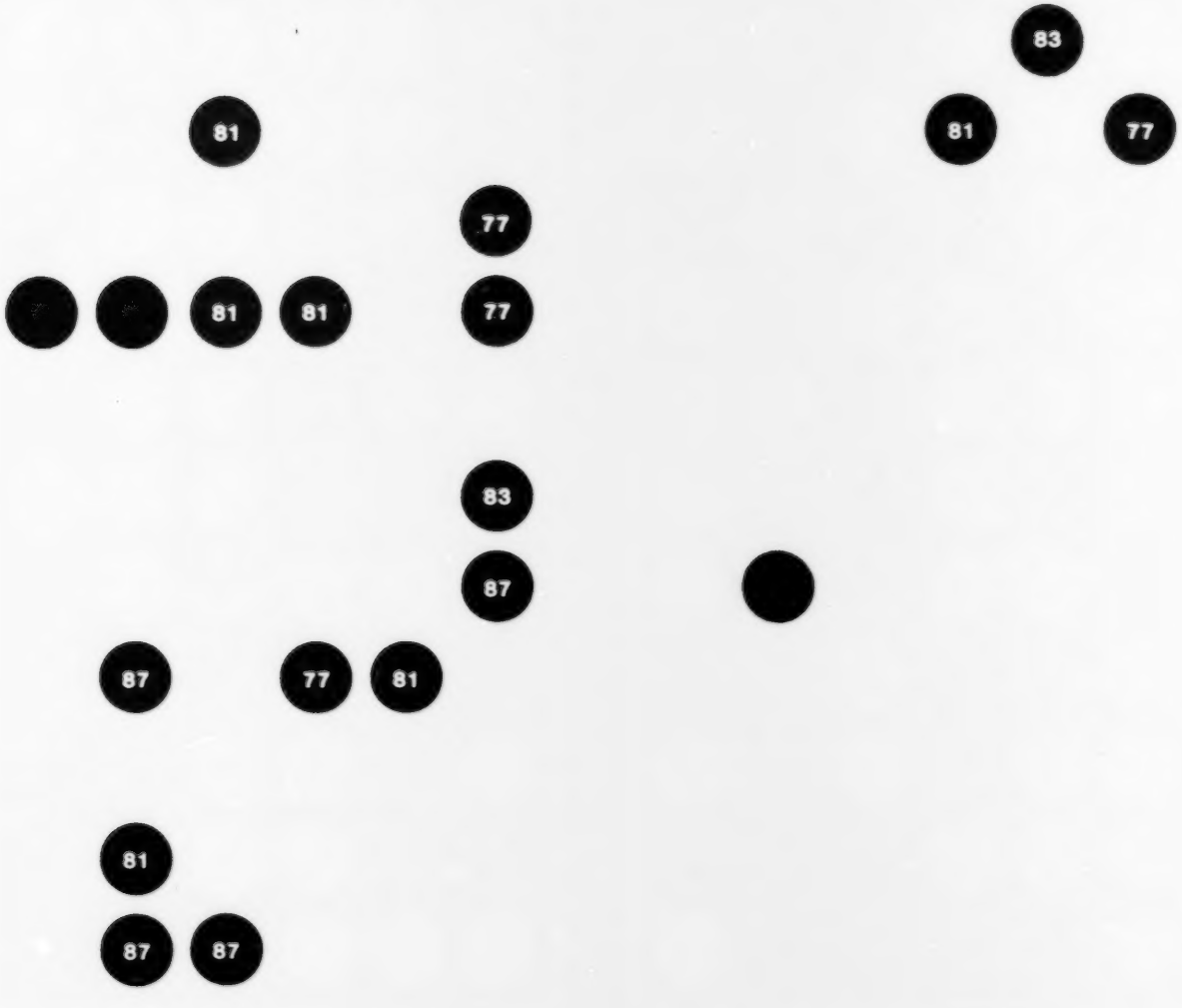

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by

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Abstract

One-half of a 2.56-ha tract in a mature Douglas-fir-lodgepole pine stand in which 60-70% of stems had been killed or were infected by *Phellinus weirii* was whole-tree logged and root raked while the other half was conventionally logged. Whole-tree logging and root raking removed almost all roots larger than 2 cm in diameter from the upper 60 cm of soil. Seedlings of Douglas-fir, lodgepole pine, western red cedar and paper birch were planted alone and in all combinations of two species in 0.04-ha plots. Tree mortality was recorded periodically over 20 years. After seedlings became established, the principal causes of mortality were the root diseases caused by *Armillaria ostoyae* and *P. weirii*. Cumulative percent mortality of Douglas-fir by *A. ostoyae* and *P. weirii* and of lodgepole pine by *A. ostoyae* was less in the treated block than in the untreated block. No lodgepole pines were killed by *P. weirii*. Plots in which rows of lodgepole pine or Douglas-fir alternate with rows of cedar or birch had fewer and smaller disease centers than plots of lodgepole pine or Douglas-fir, or both. Height and diameter growth of Douglas-fir and lodgepole pine were greater in plots in the treated block than in those in the untreated block.

Résumé

Une étendu de 2,56 ha d'un peuplement mature mixte de douglas taxifoliés et de pins tordus où 60 à 70 % des tiges avaient été tuées ou étaient infectées par *Phellinus weirii* a été coupée: la moitié par la méthode à arbres entiers avec passage subséquent d'un rateau déracineur, et l'autre moitié de façon traditionnelle. La première méthode a permis d'extirper presque toutes les racines de plus de 2 cm de diamètre qui se trouvaient dans les 60 premiers centimètres du sol. Le reboisement a été effectué avec des plants de 4 espèces (douglas taxifolié, pin tordu, thuya géant et bouleau à papier) en parcelles de 0,04 ha, ces parcelles étant plantées soit en une seule espèce, soit en deux, avec toutes les combinaisons possibles. La mortalité des arbres a été contrôlée périodiquement sur une période de 20 ans. Après la période d'implantation, les principales causes de mortalité ont été les maladies des racines causées par *Armillaria ostoyae* et *P. weirii*. Les pourcentages cumulés de douglas taxifoliés tués par *A. ostoyae* et *P. weirii* et de pins tordus tués par *A. ostoyae* étaient beaucoup plus faibles dans le bloc traité que dans le bloc témoin. Aucun pin tordu n'a été tué par *P. weirii*. Dans les parcelles où des rangées de pins tordus ou de douglas taxifoliés alternaient avec des rangées de thuyas ou de bouleaux, les foyers de maladie étaient moins nombreux et moins étendus que dans les parcelles où le pin tordu et le douglas taxifolié étaient seuls ou ensemble. L'accroissement en hauteur et en diamètre du pin et du douglas a été beaucoup plus élevé dans les parcelles du bloc traité que dans celles du bloc témoin.

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Introduction

A number of pathogenic root inhabiting fungi, *sensu* Garrett (1956), cause economically important root diseases of forest and plantation crops, worldwide. These fungi kill their hosts during the parasitic phase of their life cycle and then utilize the host tissues as a food base during the saprophytic part. Both parts of the life cycle may be from a few years to a few decades in duration, depending on characteristics of the host and pathogen and influence of environmental factors. Most of these fungi are incapable of growth through soil, hence spread from host to suscept is by mycelial transfer at points of root contact. Despite this limitation, suscepts may be exposed to inoculum for a long time because inoculum is long-lived.

The characteristics of these root diseases limit control options following harvest of a diseased crop to replanting an infested site with an immune or low susceptibility species or to reducing the amount of inoculum on the site before replanting with a susceptible species. Site factors, such as soil type, precipitation, aspect and elevation further limit the choice of species. For planting of alternate species to be effective, the diseased area must be kept free from susceptible species until the inoculum is noninfective.

Inoculum reduction has been achieved by poisoning or ring-barking trees prior to harvest, by chemically treating diseased stumps and by mechanically removing diseased stumps and roots from the soil. These methods of reducing root disease inoculum were developed for crops such as rubber, citrus, cacao and tea. Inoculum consisted of the root system of trees killed by the fungus or colonized by further development of infections present on the roots of trees felled to make way for these crops. In East Africa, Leach (1937, 1939) demonstrated that by ring-barking forest trees a year or more before felling, roots of the trees became colonized by saprophytic fungi, not by an *Armillaria* species. Similarly, Napper (1940) reported that stump-poisoning with sodium arsenite reduced colonization by *Fomes lignosus* Klotzsch when land was cleared for rubber in Malaya. However, in temperate regions ring-barking and stump-poisoning were found to be ineffective in preventing colonization of root systems of oak, *Quercus robur* L., by an *Armillaria* sp. (Redfern 1968). Bliss (1951) reported that a number of fumigants, including carbon disulfide, eradicated *Armillaria* from citrus roots. Concentrations of carbon disulfide which were sublethal for *Armillaria* predisposed *Armillaria*-colonized wood to invasion by *Trichoderma* spp. (Bliss 1951; Garrett 1957). Frequently when the above methods failed to control the root disease, inoculum was mechanically removed from the site.

Phellinus weirii (Murr.) Gilbn. and *Armillaria ostoyae* (Romagn.) Herink cause the most damaging root diseases found in southern British Columbia and the northwestern United States (Wallis 1976; Hadfield 1985; Morrison 1981; Morrison et al. 1985; Wargo and Shaw 1985). These root diseases reduce forest productivity by several million cubic meters annually (Childs and Shea 1967; Wallis 1967; Taylor 1986). During the past 20 years, much research has been done into methods of controlling these root diseases, with many research experiments and a few operational trials being established (Wallis 1976; Thies 1984). Most of the work has involved mechanical removal of inoculum from the site. Following treatment, tree mortality due to root disease, usually among several planted conifer species, is monitored over time. Roth et al. (1977) suggested combining limited removal of diseased stumps with commercial thinning to reduce losses from *Armillaria* root disease in uneven-aged ponderosa pine, *Pinus ponderosa* Laws. Recently, both fungi have been eradicated from stumps by fumigants (Filip and Roth 1977; Thies and Nelson 1982).

The Skimikin experiment, which combined inoculum removal with a species trial, is the oldest of its type in western North America. This report describes the history of the experiment, tree mortality and growth, current maintenance and management of the experiment and discusses implications of the results for management of diseased sites.

History of the experiment

The Skimikin experiment was established in 1968 by L.C. Weir to determine the efficacy of inoculum removal for control of *P. weirii*. Secondary objectives were to evaluate the resistance of several tree species to the disease and to test the effect on disease spread of alternating rows of resistant or immune species with rows of susceptible species.

The experiment is located at Skimikin (50° 48' N, 119° 26' W), near Salmon Arm, British Columbia. The area is in the Interior Cedar Hemlock biogeoclimatic zone (m_1 subzone) (Lloyd 1984) at an elevation of 750 m with a south aspect and slope of about 5%. The soil is an utric brunisol occurring on a glacial fluvial deposit. The mature stand in which the experiment was established was composed of 75% Douglas-fir, *Pseudotsuga menziesii* (Mirb.) Franco, and 25% lodgepole pine, *Pinus contorta* Dougl. var. *latifolia* Engelm., with small

numbers of western red cedar, *Thuja plicata* Donn, and Pacific yew, *Taxus brevifolia* Nutt., in the understory. The age of dominant Douglas-fir was about 80 years. Openings in the stand caused by *P. weirii* contained paper birch, *Betula papyrifera* Marsh., and trembling aspen, *Populus tremuloides* Michx. At harvest, about 20% of the Douglas-fir and lodgepole pine had been killed by *P. weirii*; post-harvest examination of stumps revealed that 60-70% of conifer stumps had stain or decay typical of *P. weirii*.

Two adjacent 80 m x 160 m blocks were laid out in the stand. In the untreated block, trees were felled and skidded to the landing in the conventional manner. On the treated block, trees were pushed over with a bulldozer and were yarded to the landing with roots attached; following tree removal this block was root-raked to a depth of 45 cm using a bulldozer fitted with a toothed, land-clearing blade. A 10 m wide strip around the blocks was cleared and root-raked to reduce the chance of root disease entering the blocks from the surrounding stand.

Each block was divided into 32 plots, each 20 m square. Douglas-fir and lodgepole pine, the species which comprised the original stand, and western red cedar and paper birch, which are resistant and immune to *P. weirii*, respectively (Wallis 1976), were selected for planting. Seedlings were planted at a 1.5 m spacing, usually with 13 rows of 13 trees in each plot. Three plots in each block were randomly selected for planting with each species alone and all combinations of two species (Fig. 1). One of the remaining two plots in each block was planted with western larch, *Larix occidentalis* Nutt., and the other with Engelmann spruce, *Picea engelmannii* Parry. Except for cedar and birch, all seedlings were nursery-grown, 2+0, bare root stock. Wildlings from the vicinity of the trial area were used for cedar and birch. Seedlings were planted early in November 1968.

Seedling survival after the first year in the treated plots averaged 85% for species other than cedar, of which only 23% were living. In contrast, only about 4% of cedar seedlings and 42% of those of other species survived in the untreated plots. The lower overall survival in the untreated block was due in large measure to competition from herbs and shrubs. In addition, the dry site, south aspect and lack of shade contributed to the poor survival of cedar, which under natural conditions becomes established only as an understory on such sites. In 1969 and 1970, seedlings which had died were replaced using similar planting stock.

Results

Amount and distribution of residual roots

To measure the effect of stump removal and root raking on the amount and distribution of residual roots, a pit approximately 2.5 m square was excavated near the location of a *P. weirii*-infected stump in the untreated block and in the scarified surround strip. The following information on all tree roots was tallied: depth (0-30 cm and 30-60 cm), diameter, length, and condition (healthy or colonized by *P. weirii*, *A. ostoyae* or other fungi) (Table 1). Whole tree logging and scarification altered the distribution of roots in the upper 60 cm of soil. In the 0-30 cm depth zone, the number, length, and volume of roots less than 1 cm in diameter was greater in the treated block for most root condition classes. In contrast, the number, length, and volume of roots more than 1 cm in diameter usually was greater in the untreated block pit. Relative to the untreated pit, almost all roots larger than 2 cm that were colonized by *P. weirii* or *A. ostoyae* had been removed from the treated pit. In the 30-60 cm depth zone, the only roots colonized by *P. weirii* and *A. ostoyae* which remained in the treated pit were less than 1 cm in diameter. The larger amounts of small diameter roots in the 0-30 cm depth zone of the treated pit suggest that some of these roots were raised from the 30-60 cm zone by scarification.

Mortality caused by agents other than root disease

In August 1973, seedling survival was assessed. No mortality due to root disease was observed; however in some plots numerous seedlings had failed to become established due to drought or competition. A stem map was prepared for each plot. The number of trees planted in 1968 and the percentage of trees living at the 1973 examination are shown in Table 2. The number of living trees in each plot in 1973 was taken as the starting point for subsequent calculations of percent mortality.

Assessments of tree condition were made in 1977, 1981, 1983 and 1987. Living trees showing signs or symptoms of insect or disease attack were noted; the cause of death was determined for all dead trees. Western gall rust, *Endocronartium harknessii* (J.P. Moore) Y. Hiratsuka, and pitch moth, *Vespamina synanthedon* Hy. Edwards, killed 1.6% and 0.5%, respectively of lodgepole pines from 1973-1987. In 1987, Douglas-fir, larch, pine and spruce were defoliated to varying degrees by western spruce budworm, *Choristoneura occidentalis* Freeman. The remaining trees in the "other" category (Table 3) died as a result of snow press, suppression, and animal damage, particularly bark

Table 1. Number, length and volume of roots per 0.1 m^3 by diameter, condition and depth classes that were removed from a 2.5-m^2 pit in the stumped and root raked (treated) block and in the untreated block

Root Condition	Diameter Class (cm)	Number of Roots		Length of Roots (cm)		Volume of Roots (cm^3)	
		Treated	Untreated	Treated	Untreated	Treated	Untreated
		0 - 30 cm Depth					
Roots colonized by *P. weirii*	<1	14.4	1.4	187	35	27	12
	1-2	0.4	1.1	5	25	9	32
	2-3	0.1	0.3	1	6	3	25
	>3	0.1	0.4	1	16	10	417
	total	15.0	3.2	194	82	49	486
Roots colonized by *A. ostoyae*	<1	7.7	1.6	88	47	12	16
	1-2	0.4	1.0	4	25	7	32
	2-3	0	0.2	0	3	0	14
	>3	0	0.2	0	5	0	115
	total	8.1	3.0	92	80	19	177
Roots colonized by other fungi	<1	18.5	1.6	196	42	24	16
	1-2	1.9	1.0	18	40	25	75
	2-3	0.4	0.5	7	17	32	85
	>3	0.1	0.1	3	1	92	10
	total	20.9	3.2	224	100	173	186
Roots healthy	<1	52.5	11.0	627	326	91	23
	1-2	3.0	0.7	42	26	63	30
	2-3	0.1	0.1	2	1	6	2
	>3	0.1	0.1	2	1	39	4
	total	55.7	11.9	673	354	199	59
Total all roots	<1	93.1	15.6	1098	450	154	117
	1-2	5.7	3.8	69	116	104	169
	2-3	0.6	1.1	10	27	41	126
	>3	0.3	0.8	6	23	141	546
	total	99.7	21.3	1183	616	440	958
		30 - 60 cm Depth					
Roots colonized by *P. weirii*	<1	2.3	3.7	35	40	5	14
	1-2	0	1.2	0	14	0	19
	2-3	0	0.1	0	2	0	12
	>3	0	0.1	0	2	0	25
	total	2.3	5.1	35	58	5	70
Roots colonized by *A. ostoyae*	<1	1.4	4.2	18	55	2	11
	1-2	0	0.3	0	4	0	4
	2-3	0	0.1	0	1	0	4
	>3	0	0	0	0	0	0
	total	1.4	4.6	18	60	2	19
Roots colonized by other fungi	<1	3.4	10.9	42	99	5	18
	1-2	0.3	0.7	4	7	5	9
	2-3	0	0.1	0	4	0	18
	>3	0	0.1	0	1	0	4
	total	3.7	11.8	46	111	10	49
Roots healthy	<1	6.6	67.0	100	867	14	80
	1-2	0.3	1.1	17	26	23	37
	2-3	0.1	0.1	2	1	8	5
	>3	0	0	0	0	0	0
	total	7.0	68.2	119	894	45	122
Total all roots	<1	13.7	85.8	195	1061	26	123
	1-2	0.6	3.3	21	51	28	69
	2-3	0.1	0.4	2	8	8	39
	>3	0	0.2	0	3	0	29
	total	14.4	89.7	218	1123	62	260

Table 2. Number of trees of each species planted in 1968 and percentage of trees established in 1973.

Tree Species	Number Trees Planted 1968		% Trees Established 1973	
	Treated	Untreated	Treated	Untreated
Douglas-fir	1137	1159	95.5	79.8
Lodgepole pine	1198	1136	94.4	94.4
Cedar	1079	1108	53.4	56.1
Birch	999	1222	49.2	19.6
Larch	165	157	72.1	82.8
Spruce	167	171	74.3	38.0

removal by squirrels feeding and deer rubbing antlers.

Mortality caused by root diseases

The principal causes of tree mortality between 1973 and 1987 were *A. ostoyae* and *P. weirii* (Table 3). In the 12 plots in each block containing Douglas-fir or lodgepole pine, cumulative percent mortality caused by these fungi was determined (Table 4). The experimental design, with one block for each treatment, did not strictly permit analysis of data using ANOVA. However, to provide an evaluation of differences between treatments, the 12 plots in each block with Douglas-fir or lodgepole pine were considered replications and cumulative mortality values were analyzed by ANOVA following application of the arcsin transformation.

Cumulative percent mortality in 1987 for *A. ostoyae* was significantly less ($P<0.01$) in the treated block than in the untreated block for both Douglas-fir and lodgepole pine (Table 4). Similarly, significantly fewer ($P<0.01$) Douglas-fir were killed by *P. weirii* in the treated block than in the untreated block (Table 4). *Phellinus weirii* has not killed any lodgepole pines. For larch and spruce, cumulative percent mortality caused by *A. ostoyae* was higher and lower, respectively, than that of Douglas-fir or lodgepole pine in both blocks (Table 4). No birch or cedar were killed by *A. ostoyae* in the treated block, while one birch (0.4%) and 13 cedar (2.1%) were killed in the untreated block (Table 4).

In addition to the analysis performed above, cumulative mortality values for Douglas-fir and lodgepole pine in the rows of plots parallel to the boundary between the blocks (Fig. 1) were compared, also by means of ANOVA. Within the blocks, these rows of plots showed insignificant variation ($P=0.90$), whereas there was a significant difference ($P<0.001$) between the blocks. Thus, the rows within blocks were relatively invariate and the marked difference between blocks is presumed to be a treatment effect and not due to chance.

In the untreated block, *A. ostoyae* mortality in Douglas-fir and lodgepole pine occurred at a constant rate of 1% per annum from 1973-1987 (Fig. 2). The mortality rate in the treated block was constant also, at 0.1% and 0.2% per annum in lodgepole pine and Douglas-fir, respectively. The relative susceptibility of the conifer species to *A. ostoyae*, as indicated by cumulative percent mortality in the untreated block, is larch, lodgepole pine, Douglas-fir, spruce and cedar.

Spatial distribution of root disease mortality

A secondary objective of the experiment was to observe the effect on disease spread of alternating rows of susceptible and less susceptible or immune species. For the untreated and treated blocks, the stem maps of nine plots with Douglas-fir or pine, or both and 12 plots with a mixture of Douglas-fir or pine and cedar or birch were examined and the number of dead trees per disease center was noted. A disease center consisted of one dead tree or two or more adjacent dead trees.

Two-thirds of disease centers caused by *A. ostoyae* contained one tree (Fig. 3). In the untreated block,

Table 3. Mortality by cause among planted trees from 1973 to 1987 at the Skimikin experiment.

Tree Species	Treatment	Live Trees 1973	Number of Trees												Live Trees 1987	Total Mortality		
			1977			1981			1983			1987						
			Ao[a]	Pw	O	Ao	Pw	O	Ao	Pw	O	Ao	Pw	O		Ao	Pw	O
Douglas-fir	Treated	1086	7		3	14	1	4	2	1	27	9		5	1013	32	2	40
	Untreated	925	19	5	3	42	15	5	25	4	5	41	16	1	744	127	40	14
Lodgepole pine	Treated	1131	5		1	6		16			23	3		14	1063	14		54
	Untreated	1072	51		1	45		12	28		8	35		15	877	159		36
Cedar	Treated	582			3			7			11			1	560			22
	Untreated	622	2		2	1			1		3	9		2	603	13		6
Birch	Treated	492						1			13			2	476			16
	Untreated	240							1		6				233	1		6
Larch	Treated	119	1			1					3	1		1	112	3		4
	Untreated	130	4			11			13			4		2	96	32		2
Spruce	Treated	124	2												122	2		
	Untreated	65	1			2			2			1			59	6		

[a] Ao = *Armillaria ostoyae*, Pw = *Phellinus weirii*, and O = other.

Table 4. Cumulative percent mortality in 1987 caused by *Armillaria ostoyae* and *Phellinus weirii* in the treated and untreated blocks.

Species	*Armillaria ostoyae*		*Phellinus weirii*	
	Treated	Untreated	Treated	Untreated
Douglas-fir	3.0a*	14.8b	0.2a	4.7b
Lodgepole pine	1.3a	15.8b	0	0
Larch+	2.5	27.0	0	0
Spruce+	1.6	9.4	0	0
Cedar+	0	2.1	0	0
Birch+	0	0.4	0	0

* For each species and disease, values followed by a different letter are significantly different (P<0.01).
+ Significance of differences between means was not tested.

1 FIR BIRCH	16 FIR	17 CEDAR BIRCH	32 LARCH	33 CEDAR	48 PINE CEDAR	49 PINE BIRCH	64 FIR BIRCH
2 FIR CEDAR	15 PINE BIRCH	18 PINE CEDAR	31 BIRCH	34 PINE BIRCH	47 FIR PINE	50 PINE	63 SPRUCE
3 BIRCH	14 FIR PINE	19 PINE	30 FIR	35 CEDAR BIRCH	46 CEDAR	51 FIR CEDAR	62 PINE CEDAR
4 CEDAR	13 CEDAR BIRCH	20 PINE CEDAR	29 FIR PINE	36 FIR	45 FIR BIRCH	52 BIRCH	61 FIR
5 SPRUCE	12 CEDAR	21 FIR BIRCH	28 PINE BIRCH	37 FIR CEDAR	44 BIRCH	53 FIR BIRCH	60 PINE
6 FIR CEDAR	11 BIRCH	22 PINE CEDAR	27 FIR	38 PINE CEDAR	43 CEDAR BIRCH	54 PINE	59 FIR PINE
7 CEDAR BIRCH	10 PINE	23 PINE BIRCH	26 FIR BIRCH	39 FIR	42 FIR CEDAR	55 CEDAR BIRCH	58 BIRCH
8 FIR PINE	9 CEDAR	24 FIR CEDAR	25 PINE	40 FIR PINE	41 LARCH	56 CEDAR	57 PINE BIRCH

Figure 1. Planting design. (Plots 1-32 = treated block and plots 33-64 = untreated block.)

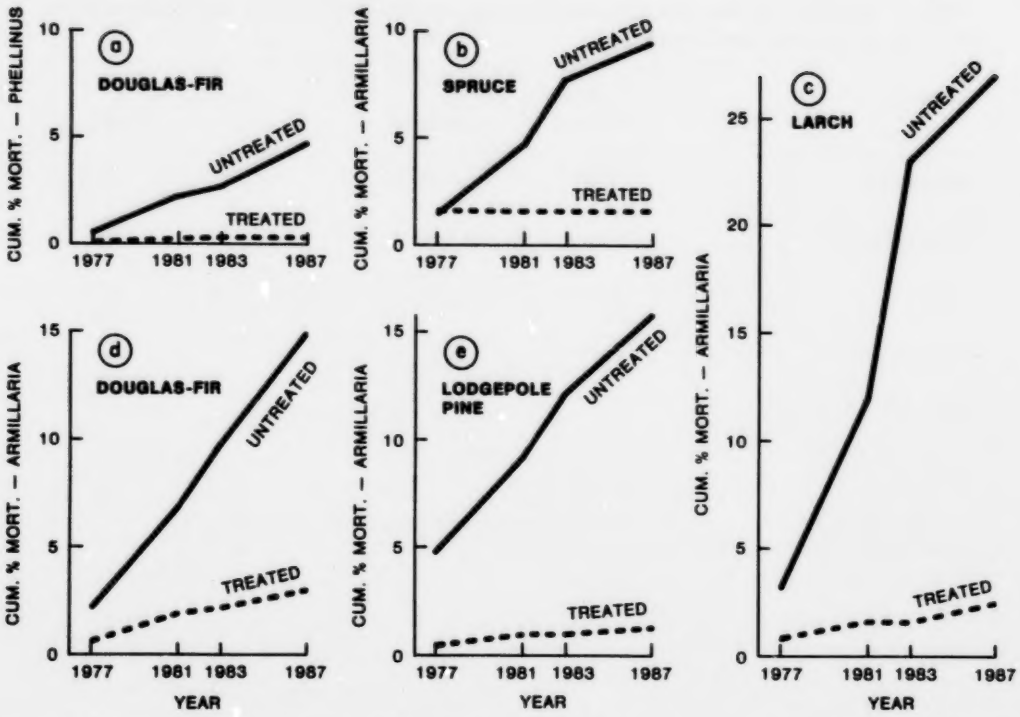

Figure 2. Cumulative percent mortality of Douglas-fir, lodgepole pine, spruce and larch caused by *Armillaria ostoyae* and of Douglas-fir by *Phellinus weirii* in treated and untreated blocks between 1973 and 1987.

Douglas-fir, pine and fir-pine plots had more centers with two or more trees than plots with rows of fir or pine alternating with rows of cedar or birch. Except for four centers in two fir-cedar plots, centers in mixed fir or pine and cedar or birch plots were confined to rows of fir or pine.

The stumping treatment reduced the number of one- and two-tree centers and no centers with three or more trees developed. Again, alternating rows of fir or pine and cedar or birch prevented spread between rows, reducing the number of disease centers.

The two trees killed by *P. weirii* in the treated block were in one-tree centers. In fir-birch and fir-cedar plots in the untreated block, all spread of *P. weirii* was along fir rows.

Growth of Douglas-fir and lodgepole pine

In 1987, dbh and height were measured on four randomly selected dominant or codominant trees of each conifer species (except cedar) in each plot. The 48 Douglas-fir and 48 lodgepole pine measured in each block were analyzed separately for dbh and height by ANOVA. For both species, dbh and height were significantly greater ($P < 0.01$) in the treated block than in the untreated block (Table 5). The mean height and diameter of spruce and larch (except larch dbh) also were greater in the treated block (Table 5). The diameter and height growth of larch was superior to that of the other conifers.

Current maintenance

Due to the close spacing of trees, particularly in plots with more than 80% survival (Table 2), crown closure and differentiation into crown classes had occurred, making stocking control desirable. Following assessment of mortality in 1987, two plots of each species or species combination were thinned, where necessary. Crop tree selection criteria were stem form, crown class and location; the desired tree spacing was 3 m x 3 m. In two of the three plots of Douglas-fir or lodgepole pine with alternate rows of birch or cedar, the latter were removed. The third plot of each species or species combination was left unthinned. The single plots of larch and spruce in each block were spaced. Following thinning, all residual trees were tagged.

Table 5. Mean DBH and height of four dominant or codominant Douglas-fir, lodgepole pine, spruce and larch trees per plot in the treated and untreated blocks.

Tree Species	DBH (cm)		Height (m)	
	Treated	Untreated	Treated	Untreated
Douglas-fir	12.2a*	11.0b	9.7a	8.1b
Lodgepole pine	11.0a	10.2b	8.6a	7.0b
Spruce+	7.5	7.4	5.9	5.7
Larch+	14.0	14.7	13.3	11.8

* Means for DBH and height of each species followed by a different letter are significantly different ($P < 0.01$).

+ Significance of differences between means was not tested.

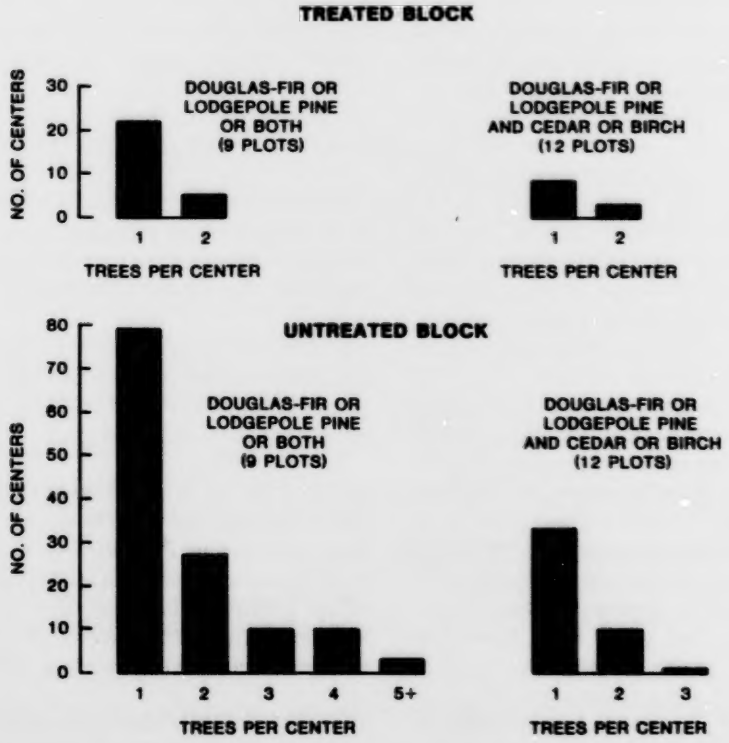

Figure 3. Number of *A. ostoyae* centers containing 1, 2, 3, 4 and 5 or more trees in plots of Douglas-fir or lodgepole pine, or both and plots of Douglas-fir or pine and cedar or birch.

Tree condition and growth will be assessed at intervals of 4 or 5 years.

Discussion

The Skimikin experiment was intended to test the efficacy of stump removal for control of *P.weirii*.. A pre-establishment survey of the area indicated that 60-70% of conifers were infected by *P. weirii*. However, during the first 20 years of the experiment, the principal cause of tree mortality has been *A. ostoyae*, not *P. weirii*. The amount of *A. ostoyae* mortality and the presence of roots colonized by the fungus in pits dug to measure residual roots suggest that a large amount of *A. ostoyae* inoculum was on the site. In 1968, the generally held view among pathologists was that *Armillaria* (referred to then as *A. mellea)* was secondary on trees attacked by *P. weirii* or predisposed by another agent. This may account for the absence of records of *Armillaria* root disease incidence in the original stand.

Although the epidemiology of *A. ostoyae* and *P.weirii* is similar in many respects, there are several important differences, especially the ability of *A. ostoyae* to produce rhizomorphs. To become infected by *P. weirii* a root of a suscept must grow in contact with inoculum; the suscept may be infected by *A. ostoyae* in the same manner or by a rhizomorph growing to contact a root of the suscept. For a number of years after plantation establishment, rhizomorphs are the principal means whereby trees are infected. Rhizomorphs produced by large stumps colonized by *A. ostoyae* may infect several trees planted around the stump. Lethal infections caused by rhizomorphs usually are within 30 cm of the food base producing the rhizomorph (Morrison, unpublished results). The amount of rhizomorphs produced from woody inoculum is related to the size, particularly diameter (Morrison, unpublished results), the density of the wood and the tree species (Rishbeth 1972). Inocula less than 1 cm in diameter produce few rhizomorphs and *A. ostoyae* in them is replaced by saprophytic fungi in a few years. As trees become older and their resistance to infection increases, the inoculum potential of rhizomorphs is inadequate to initiate progressive infections. Coincidentally, root contacts develop between adjacent trees and the fungus may spread from diseased to healthy trees at points of root contact.

Prior to development of contacts between adjacent trees, trees killed by *P. weirii* had been planted very close to inoculum. If the inoculum is small, both it and the killed tree are exhausted as food bases for *P. weirii* in a few years and the fungus is replaced by saprophytic fungi before roots of adjacent trees contact the inoculum. In the treated block, the two trees killed by *P. weirii* in 1981 and 1983 were single tree centers; to date, adjacent trees have not become infected. Of the 20 *P. weirii* centers in the untreated block, eight were noted first in 1987. These centers probably developed when tree roots contacted inoculum in large stump roots. Recent mortality by *P. weirii* in the remaining twelve centers has resulted from root contact between adjacent trees. Incidence of mortality due to *P. weirii* is expected to increase in the untreated block, the trees having reached an age where root contacts are common.

There is little difference among conifer species in susceptibility of seedlings and young trees to *A. ostoyae* (Morrison 1982). Resistance to *A. ostoyae* increases with age, albeit unequally, for all conifer species until, by age 40 years, susceptibility in decreasing order is Douglas-fir, spruce, cedar and larch (Morrison 1981). This is in contrast to species susceptibility indicated by cumulative percent mortality (Table 4), where larch was most susceptible. Mortality among larch declined between 1983 and 1987 and should continue to decline. Unlike larch, Douglas-fir, lodgepole pine and spruce are killed by *A. ostoyae* throughout the rotation in the southern interior of British Columbia (Morrison 1981). Hence, mortality in plots of these species is expected to continue. It is noteworthy that the rate of mortality for Douglas-fir has not begun to decrease, unlike that recorded in coastal plantations (Johnson et al. 1972).

Wallis (1976) lists Douglas-fir as susceptible to *P. weirii*, lodgepole pine and cedar as moderately to highly resistant and broadleaved species as immune. Results of this experiment support his ranking.

The differences in epidemiology noted above account for differences between the two diseases to date in incidence of mortality and in size of disease centers, particularly in the untreated block.

Although limited, data on residual roots from the pits in the stumped and root-raked block indicate that residual roots colonized by *P. weirii* and *A. ostoyae* were of small diameter and hence, of limited value as inoculum, except perhaps in the short term. The significantly lower mortality in the treated block is due to the removal of large inocula by whole-tree logging and root-raking.

The better survival of planted seedlings and the significantly greater growth of Douglas-fir and lodgepole pine in the treated block are a result of reduced competition from herbs and shrubs and perhaps of improved soil nutrient status through mixing of organic matter. In

Idaho, scalping (Sloan and Riker 1986) and slashing of residual understory trees and shrubs (Cole and Schmidt 1986) reduced competition and resulted in greater height growth of several conifer species.

For sites where stump removal is impracticable due to soil type, topography, or other reasons, planting the most resistant species suited to the site or planting alternate rows of susceptible and less susceptible or immune species should yield a stand with acceptable stocking. These plots contain about one-half as many susceptible trees as the plots of fir or pine, or both and this may account, in part, for the smaller number of disease centers; as well, the greater distance between rows of susceptible trees may delay root contact with inoculum until it is noninfective. Although the results for alternate rows of susceptible and less susceptible species are for only 20 years of an 80 year rotation, they suggest that disease spread between rows of susceptible species is reduced.

Conclusions

Whole-tree logging and root-raking significantly reduced mortality caused by *A. ostoyae* and *P. weirii* by removing large diameter inocula from the soil and significantly increased the growth of Douglas-fir and lodgepole pine. The additional cost of the treatment is justified and compensated by the reduced losses to root disease, improved tree growth and full, uniform stocking.

Where stump removal is impracticable, larch is the preferred species on sites infested by *A. ostoyae*, because of the resistance which develops after about age 20. Mortality in young larch could be reduced by alternating rows of larch and cedar, site permitting.

Similarly, on sites infested by *P. weirii*, lodgepole pine should be planted where hazard is high; alternate rows of Douglas-fir and lodgepole pine could be planted where hazard is low.

When both diseases occur on a site, a mixture of lodgepole pine and larch has the best chance of producing a stocked stand.

The results of this study may be applied in the southern interior of British Columbia.

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